

Definition of Standard Office Environments for Evaluating the Impact of Office Furniture Emissions on Indoor VOC Concentrations

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ABSTRACT

A representative “worst-case” office environment, which defines the size and volume of the office space, the amount and type of office furniture surface area, and the outdoor, clean airflow rate is necessary to estimate the impact of office furniture emissions on indoor VOC concentrations based on the emission rates measured from chamber tests. In this study, 31 randomly selected floor plans from North American office buildings were analyzed in detail. The floor plans were from projects in late 2004 and early 2005 and were provided by an industry cross section of seven major office furniture manufacturers. The analysis included documenting the potential emitting surface area for each workstation and a determination of how much common office space (aisles, etc.) was present and shared between workstations and other adjoining spaces. The 90th percentile conditions for total furniture surface area within the 50th percentile workstation footprint sizes were identified from the more than 5000 workstations analyzed to provide a representative “worst-case” office environment model (i.e., occupant exposure scenario).

Based on the analysis, the representative “worst-case” standard **open plan** office environment for a single workstation system is defined as 5.94 m² (64 ft²) floor area by 2.74 m (9 ft) high (576 ft³ or 16.3 m³), accounting for a standard 1.83 m × 1.83 m (6 ft × 6 ft) open plan workstation system, traffic area, and support space for shared copiers, files, storage, etc. The space is assumed to be occupied by a single occupant and has an outdoor or clean air ventilation rate of 4.17 L/s (8.84 cfm), in accordance with ASHRAE Standard 62.1-2004. The representative “worst-case” standard **private** office environment for a single workstation system is defined as 23.78 m² (256 ft²) floor area by 2.74 m (9 ft) high (2304 ft³ or 65.2 m³), accounting

for a standard 13.38 m² (144 ft²) private office workstation system, traffic area, and support space for shared copiers, files, storage, etc. The space is assumed to be occupied by a single occupant and has an outdoor or clean air ventilation rate of 9.63 L/s (20.4 cfm) in accordance with ASHRAE Standard 62.1-2004. A comparison to historical office environment models is included.

INTRODUCTION

An evolving variety of sometimes conflicting test methods, model office environments, and requirements for modeling volatile organic compound (VOC) emissions from office furniture have been specified by various US organizations from 1989 to the present (Washington 1989; US EPA 1996; US EPA 1999; California 2000; Greenguard 2001; California 2004; USGBC 2004; BIFMA 2005a, 2005b; SCS 2005; California 2006). In these varied programs, environmental chamber testing of office furniture workstations or components is used to determine the emission rates, which are in turn used to estimate the impact of the workstation system on the VOC concentration levels in actual buildings by using a prescribed office environment model (i.e., occupant exposure scenario). Some of these programs define office environment models that are intended to be representative of specific buildings (Washington 1989; US EPA 1996; California 2000), while others do not contain any office environment model (US EPA 1999). The proliferation of office furniture emission programs with varied and potentially outdated office environment models raises questions as to how well the models represent actual building environments and makes it extremely difficult to compare VOC emissions performance across the broad variety of office furniture types available today.

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The objective of this study is to define a standard, representative “worst-case” office environment model for new office furniture used in North American office buildings. This office environment model is intended to be used to provide a common basis of comparison for a broad variety of office furniture to relevant emissions requirements. These comparisons to requirements generally occur when estimating the impact of office furniture emissions on indoor VOC concentrations using the results of environmental chamber emissions testing. This study was conducted jointly with a working group of the Business and Institutional Furniture Manufacturers Association (BIFMA)¹ International, Furniture Emissions Standard (FES) Subcommittee, in support of the development of the BIFMA M7.1-2005 standard test method.

In 1994 the United States General Services Administration (GSA) requested that BIFMA develop a harmonized, voluntary, open consensus standard for office furniture emissions testing. Work began and in 1998 BIFMA filed public notice through the ANSI Project Initiation Notification System (PINS) announcing the ongoing development of a draft ANSI standard for office furniture emissions. In parallel with this work, BIFMA, along with the US Environmental Protection Agency (EPA), the Research Triangle Institute, and other relevant stakeholders, helped to develop the US EPA 1999 test protocol for large chamber emissions testing of office furniture. BIFMA FES work continued, reaffirming the ANSI PINS for office furniture emission standards in 2004 and leading to a test method development project, including this study, which was conducted in 2005. The results of this study have been incorporated into the BIFMA M7.1-2005 test method, which was issued by BIFMA following industry consensus in September 2005 and adopted as an alternative compliance path within the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design for Commercial Interiors (LEED-CI) Environmental Quality (EQ) credit 4.5 for low-emitting furnishings on July 12, 2006. The state governments of California and Minnesota have incorporated the BIFMA M7.1 test method into their respective procurement specifications for office furniture. Scientific Certification Systems (www.scs-certified.com) has also adopted the BIFMA M7.1 test method as part of their Indoor Advantage™ certification program.²

An office environment model defines the size and volume of the office space, the amount and type of office furniture surface area, and the outdoor, clean airflow rate. In this study, 31 randomly selected floor plans from North American office

buildings were analyzed in detail. The floor plans were from current projects (late 2004 and early 2005) and were provided by an industry cross section of seven major office furniture manufacturers (see “Acknowledgments”). The analysis included documenting the potential emitting surface area for each workstation and determining how much common office space (aisles, etc.) was present as shared between workstations and other adjoining spaces. The 90th percentile conditions for total furniture surface area within the 50th percentile workstation footprint sizes were identified from the more than 5000 workstations analyzed, to provide a representative “worst-case” office environment model for estimating the impact of office furniture emissions on VOC concentrations.

This study is based on analysis of office floor plan drawings and related furniture dimensions. These drawings did not include measurements or specifications of ceiling heights or the airflow levels present in each building. Therefore, the requirements of ANSI/ASHRAE Standard 62-2001 and ANSI/ASHRAE Standard 62.1-2004 were used to determine the minimum amount of outdoor, clean airflow required in order to determine a representative “worst-case” office environment model. The two ASHRAE 62.1 standards were used because most US jurisdictions specify ASHRAE 62 as a minimum legal ventilation requirement within building codes and the USGBC has specified ANSI/ASHRAE Standard 62.1-2004 as a prerequisite requirement for LEED projects. For determinations of office volume, a 2.74 m (9 ft) ceiling height has been assumed as a representative “worst-case” condition. The authors note the Standard 62.1 criteria and the emissions concentration calculations are based on steady-state environments, which are dependent on airflow rates (cfm or L/s) and not room volumes.

THE OFFICE ENVIRONMENT MODEL—THE MISSING FACTORS

The office environment model is used to estimate the impact of office furniture emissions on indoor VOC concentrations using the following equation (reference BIFMA M7.1-2005, Section 6.6).

Equation 1 calculates the VOC concentration in the office environment due to the measured emissions from an office workstation system.

$$C(t) = \frac{A_o E(t)}{Q_o} \quad (1)$$

where

- $C(t)$ = VOC concentration in the defined office environment at the time (t) of interest, mg/m³
- A_o = source amount of office furniture workstation, i.e., emitting surface area present, m²
- $E(t)$ = measured emission factor of office workstation at time (t) of interest, mg/(m² h)
- Q_o = the outdoor, clean air ventilation flow rate in the office environment, m³/h

¹ BIFMA is a not-for-profit trade association of furniture manufacturers and suppliers working together in a cooperative forum on issues of common concern. BIFMA has been an American National Standards Institute (ANSI) accredited standards developer for over 20 years and currently maintains eight voluntary American National Standards for furniture. Additional detail is available at www.bifma.org.

² As of March 2007, BIFMA was nearing completion of formal ANSI approval of the BIFMA furniture emissions standards.

The VOC concentration $C(t)$ due to office furniture can be calculated, and the emission factor $E(t)$ can be measured from chamber testing, but the challenge is to determine the appropriate amount of emitting surface area A_o and the outdoor, clean air ventilation flow rate Q_o to use in the office environment exposure model. From Equation 1 it is evident that more emitting surface area A_o will result in a higher VOC concentration, while more outdoor, clean airflow Q_o will result in a lower VOC concentration. Therefore, it is necessary to determine the representative “worst-case” conditions for both A_o and Q_o in combination, i.e., under what reasonable conditions will there be the most office furniture surface area with the least amount of outdoor, clean airflow?

Determination of Outdoor, Clean Airflow Rate Q_o

US building codes define the minimum legal requirements for building design and construction. While each jurisdiction or municipality is responsible for determining their specific requirements, the vast majority adopt existing model codes or standards. Specifically for building ventilation, most jurisdictions establish minimum criteria based on ASHRAE standards. The most widely adopted model code for building mechanical heating, ventilating, and cooling systems, the International Code Council’s *International Mechanical Code* (IMC 2003) specifies in Section 403 that building ventilation systems must provide a minimum outdoor, clean airflow rate to occupied spaces based on room occupancy type³ (e.g., office, conference room, corridor, kitchen, etc.) and occupant density (i.e., persons present per unit of net occupiable floor area) as defined in ASHRAE Standard 62-2001. Future revisions of building codes are expected to adopt the ASHRAE 62.1-2004 standard. As previously mentioned, the USGBC LEED program (USGBC 2004) has also adopted the ASHRAE 62.1-2004 standard as a prerequisite requirement for receiving the 15 possible points under “Indoor Environmental Quality.”

ASHRAE 62-2001 requires a minimum of 10 L/s per person (20 cfm per person) of outdoor, clean air ventilation for office spaces. ASHRAE 62-2001 also specifies an estimated maximum occupant density for office spaces of seven people per 100 m² or 1000 ft² of net occupiable space. However, the Ventilation Rate Procedure in ASHRAE 62.1-2004, Section 6, determines the minimum outdoor, clean air ventilation rate using Equation 2, the ASHRAE 62.1-2004 calculation of minimum required outdoor airflow:

$$V_{bz} = R_p P_z + R_a A_z \quad (2)$$

where

V_{bz} = outdoor, clean airflow rate required in the breathing zone of the occupiable space(s)

3. Additional guidance regarding the practical application of the ICC *International Mechanical Code* requirements for outdoor, clean air ventilation rates is available in the book, *2003 IMC Fundamentals*, also available from the International Code Council.

- R_p = outdoor, clean airflow rate required per person, 2.5 L/s per person (5 cfm per person) for office spaces
- P_z = population, the number of persons expected to occupy the zone during typical usage
- R_a = outdoor, clean airflow rate required per unit area, 0.3 (L/s)/m² (0.06 cfm/ft²) for office spaces
- A_z = zone floor area: the net occupiable floor area of the zone, m² (ft²)

ASHRAE 62.1-2004 also specifies a default occupant density for office spaces of five people per 100 m² or 1000 ft² of net occupiable space when actual occupant density is not known.

Comparing ASHRAE 62-2001 and ASHRAE 62.1-2004, the minimum required outdoor, clean airflow ventilation rates are determined differently. While ASHRAE 62-2001 requires 20 cfm of outdoor, clean air per person regardless of occupant density, ASHRAE 62.1-2004 varies the requirement for outdoor, clean air in an office space by both the number of occupants present and the office floor area per person in the space, as shown in Figure 1.

Assuming that each office workstation is intended for a single person (an assumption that is conservative for larger workstations with more space that may be used for meetings), office spaces with lower occupant density (depicted on the right side of Figure 1) have correspondingly larger workstations and therefore have the potential for correspondingly larger furniture emitting surface areas. Similarly, office spaces with higher occupant densities (depicted on the left side of Figure 1) have correspondingly smaller workstations and due to limited space will have correspondingly smaller furniture emitting surface areas.

Under ASHRAE 62-2001 with a constant 20 cfm per person of outdoor, clean air requirement, regardless of occupant density or workstation size, the representative “worst-case” condition would tend to be larger workstations with low occupant density and the potential for more furniture surface area. However, under ASHRAE 62.1-2004, which requires more outdoor, clean air ventilation for larger workstations,

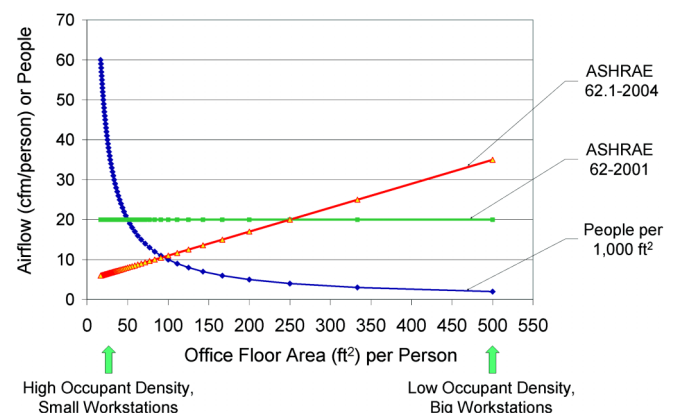


Figure 1 Outdoor, clean air required in offices.

with potentially more furniture surface area and less outdoor, clean air ventilation for smaller workstations with correspondingly less furniture surface area, neither larger nor smaller workstations provide an obvious representative “worst case” condition for potential furniture emission concentration. Considering new office workstation sizes (described in the next section), ASHRAE 62.1-2004 is a more stringent requirement and was chosen to determine the outdoor, clean airflow rate Q_o , as the vast majority of new office workstations are smaller than 250 ft², which would result in a ventilation rate less than 20 cfm/person (Figure 1).

Investigation of Office Workstation Size

Conceptually, the office environment model can be considered to be a room, ventilated with some outdoor, clean airflow rate, and containing a single office workstation with an amount of common office space distributed around the workstation for aisles, shared copiers, storage, etc. As with airflow, the amount and type of office furniture surface area present is dependent on the size of the office space. Therefore, it is necessary to determine the floor area per workstation and floor area of associated common office space.

Various sources of research exist regarding the size of office workstations in existing buildings (IFMA 1997, 2002; Veitch 2003; Persily and Gorfain 2004); however, the authors could not identify existing research that specifically addressed office workstation sizes for buildings with new furniture (representing new office workstation applications and trends). Existing research and office furniture manufacturer experience firmly supports the trend that installed office workstation footprints have been shrinking. “Eight years of research by the International Facility Management Association (IFMA) shows that, across the board in all categories, workers in US offices have been forced to adapt to progressively less space. Surveys of facility professionals in 1994, 1997 and 2002 show that the average amount of square footage allotted to each worker has decreased continuously” (IFMA 2004).

Given the open plan nature of many office buildings, workstations and the surrounding “common” space are affected by the contents, dimensions, and configuration of the entire office floor plan. US building code and ASHRAE ventilation criteria are also directly affected by the entire floor plan. Therefore, the analysis of workstation size necessarily began with office building floor plans. A working group of volunteers from the BIFMA Furniture Emissions Standard subcommittee, representing seven major office furniture manufacturers, agreed to provide and help analyze a random sample of customer floor plans from late 2004 to early 2005 projects. At the time plans were selected, the analysis plan had not been fully defined or completed and participants did not know what effect large or small buildings, large or small workstations, or other variable parameters could have on the analysis. Participants were asked to randomly select floor plans from current projects but to focus on plans that

contained as much dimensional detail as possible of all included office furniture.

To maintain consistency within the analysis of floor plan area and to apportion any common office space to adjoining areas likely to share ventilation, the following steps were conducted for each floor plan.

First, determine the *total usable floor area*. Considering the ASHRAE 62.1-2004 definition for *net occupiable space* and reviewing definitions for *usable floor area* from existing office building floor area measurement standards (ANSI/BOMA 1996; ASTM E1836-01), for purposes of this study *total usable floor area* is defined as gross interior building area minus major vertical penetrations minus building common area. Vertical penetrations typically include stairwells, elevators, plenum shafts, etc. Building common area provides services to building tenants but is not located within the office area of any specific tenant and typically includes utility/mechanical rooms, restrooms, janitor closets, lobbies, etc. Also exclude occupiable non-office areas, such as cafeterias and kitchens, unless they were immediately adjoining (i.e., are open to or have doors that open directly into) the *general office common space* (see Figure 2). General office common space usually functions as a walkway or aisle, and may be used as an open conference/gathering area, fax/copier work area, or a combination of similar functions. If occupiable non-office areas are immediately adjoining, then treat these spaces as another “area of interest” when apportioning general office common space unless the doors separating these spaces from the general office common space would normally be closed the vast majority of the time (e.g., public reception areas or corridors outside elevators in multiple-story buildings with multiple tenants).

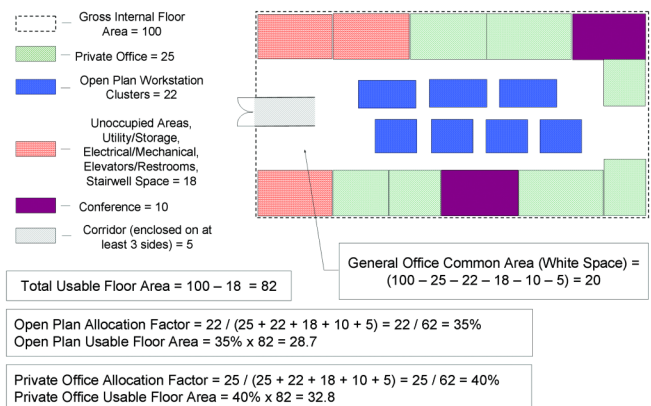


Figure 2 Floor plan area calculation example. *Note:* Drawing is not to scale or indicative of actual floor plans. All values are in thousands of square feet and are hypothetical to illustrate calculations. For this example, total “areas of interest” = (25 + 22 + 18 + 10 + 5) = 62.

Second, determine the *total conference room floor area* of all conference rooms shown on the plan and the *total corridor floor area* of all floor-to-ceiling corridors shown on the plan. Exclude conferencing areas that are part of a private office or an open plan area. Corridors must be enclosed on at least three sides with floor-to-ceiling walls or doors.

Third, calculate the *open plan usable floor area* and *private office usable floor area*. The *open plan usable floor area* is the total floor space occupied by all open plan workstations, plus a proportionally allocated portion of the general office common space. To calculate the *open plan usable floor area*, the total space occupied by all open plan workstations is divided by the total floor space of all “areas of interest” and then multiplied by the *total usable floor area* (see Figure 2).

“Areas of Interest” are occupiable building areas (e.g., private offices, floor-to-ceiling conference rooms, pure corridor space, etc.) that immediately adjoin the general office space, usually surrounding open plan offices or immediately adjacent to private offices. *Private office usable area* is calculated similarly but uses total floor space occupied by all private offices instead of open plan workstations. To allow apportioning of general office common space to individual open plan and private office workstations, the ratio specific to each floor plan of common area apportioned to the open plan and private offices is calculated as shown in Equation 3. The resulting floor area data for each building floor plan are shown in Tables 1 and 2.

Table 1. Floor Area—Measured Values from Building Floor Plans

Floor Plan	Total Usable Floor Area, ft ²	Total All Private Conference Room Area, ft ²	Total All Enclosed Corridor Area, ft ²	Total Other Adjoining, Occupiable Areas of Interest, ft ²	Total Open Plan Workstation Area, ft ²	Total Private Office Area, ft ²	Total Number of Workstations Present on Plan
1	1608	399	328	0	0	550	5
2	3281	361	263	0	1405	439	25
3	4231	1000	375	0	0	1056	8
4	6592	120	780	1120	2865	627	50
5	7328	370	60	52	2281	1545	33
6	7625	850	775	2289	289	300	4
7	7747	400	94	0	1700	1344	36
8	8297	0	0	630	1872	1593	52
9	8329	445	0	414	4193	580	90
10	8446	0	0	0	2844	0	73
11	8493	1673	180	0	2800	780	55
12	9329	1825	930	0	1690	580	37
13	11,386	2050	1200	0	384	2125	16
14	11,408	666	300	0	1536	2120	41
15	11,710	0	179	0	3782	1712	78
16	12,330	2412	0	1544	4570	1556	116
17	13,402	0	749	3245	2560	1972	58
18	14,177	809	0	347	3509	2475	119
19	14,898	1219	91	318	6642	1016	93
20	16,756	820	129	2632	2599	5092	65
21	20,972	1615	336	270	7856	858	110
22	21,174	1578	132	576	5712	600	214
23	21,970	1125	0	0	1152	8320	40
24	27,308	1155	0	309	7013	7275	140
25	30,750	1059	0	1136	4238	3912	115
26	34,127	1057	0	8073	1274	8423	90
27	39,595	1008	0	0	13,063	4365	416
28	40,315	2345	2249	4196	14,674	380	430
29	45,781	1367	487	512	21,672	4608	416
30	70,918	6927	2370	3441	21,856	2089	818
31	100,614	7194	0	6690	35,285	3518	995

Table 2. Floor Area—Calculated Values from Building Floor Plans

Floor Plan	Open Plan Usable Floor Space, ft ²	Private Office Usable Floor Space, ft ²	Total Common Office Area, ft ²	Common Area Apportioned to Open Plan, ft ²	Common Area Apportioned to Private Offices, ft ²	Common Area Added to Open Plan as Percent of Open Plan Area	Common Area Added to Private Offices as Percent of Private Office Area
1	0	693	331	0	143		26%
2	1867	583	812	462	144	33%	33%
3	0	1838	1800	0	782		74%
4	3426	750	1080	561	123	20%	20%
5	3880	2628	3020	1599	1083	70%	70%
6	489	508	3122	200	208	69%	69%
7	3723	2943	4209	2023	1599	119%	119%
8	3793	3227	4202	1921	1634	103%	103%
9	6201	858	2698	2008	278	48%	48%
10	8446	0	5602	5602	0	197%	
11	4377	1219	3061	1577	439	56%	56%
12	3138	1077	4304	1448	497	86%	86%
13	759	4201	5627	375	2076	98%	98%
14	3791	5233	6786	2255	3113	147%	147%
15	7807	3533	6038	4025	1822	106%	106%
16	5590	1903	2249	1020	347	22%	22%
17	4024	3099	4876	1464	1128	57%	57%
18	6968	4914	7037	3459	2439	99%	99%
19	10,656	1629	5612	4014	614	60%	60%
20	3863	7570	5485	1265	2478	49%	49%
21	15,067	1646	10,037	7211	788	92%	92%
22	14,067	1478	12,576	8355	878	146%	146%
23	2388	17,249	11,373	1236	8929	107%	107%
24	12,157	12,612	11,557	5145	5337	73%	73%
25	12,598	11,627	20,405	8360	7716	197%	197%
26	2,309	15,268	15,300	1035	6845	81%	81%
27	28,055	9375	21,159	14,992	5010	115%	115%
28	24,811	642	16,471	10,137	262	69%	69%
29	34,635	7364	17,135	12,963	2756	60%	60%
30	42,253	4039	34,235	20,397	1950	93%	93%
31	67,382	6718	47,928	32,097	3200	91%	91%

Equation 3 calculates the apportioned common area as percent of open plan or private office.

$$\text{Common area percent added} = \frac{\text{Common area apportioned to open plan or private office}}{\text{Total open plan or private office workstation area}} \quad (3)$$

Additional floor plans with insufficient data were analyzed but are not included here.

For each building floor plan, the floor area (i.e., footprint) of each workstation was determined. For open plan workstations, the floor area was defined as the area of the overall

dimensions of the extent of the workstation in plan view (i.e., viewed from the ceiling) and is shown in Figure 3. For private office workstations (private offices with floor-to-ceiling walls) the floor area was defined as the floor area of the office enclosing the workstation and is shown in Figure 4.

Determination of Office Furniture Workstation Emitting Surface Area A_o

As with workstation sizes in new buildings, the authors could not identify existing research that provided detailed dimensions of newly installed office workstation furniture to allow analysis of the furniture surface area present. Therefore,

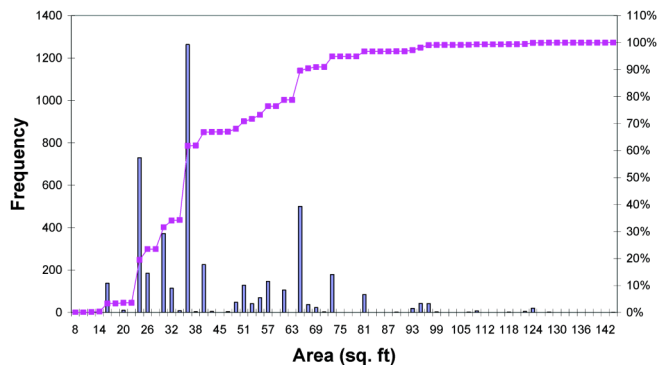


Figure 3 Open plan workstation floor area (without apportioned common office space; $n = 4594$).

this study included determining the potential emitting surface areas (i.e., total of all major surface areas) of the workstations present on the office building floor plans analyzed.

Because ASHRAE 62.1-2004 was determined to be the most stringent and current standard to determine the minimum required outdoor, clean airflow rate Q_o and neither larger nor smaller workstations necessarily represent a “worst-case” emissions condition under ASHRAE 62.1-2004, the 50th percentile workstation size was selected as most closely representing actual office conditions for more buildings. As total workstation surface area varies within workstations of identical floor area and more surface area increases the potential for higher concentrations, the 90th percentile conditions for total furniture surface area within the 50th percentile workstation footprint sizes were chosen to provide a representative “worst-case” office environment.

For the purposes of this study, *total workstation surface area* is defined as the sum of vertical *panel surface area*, horizontal *work surface area*, and *storage external surface area*. Using 90th percentile conditions for total workstation surface area aligns with current office furniture emissions requirements, which specify criteria based on whole workstations (USGBC 2004; Greenguard 2001; BIFMA 2005; SCS 2005). Determining emissions criteria for subsets of total workstation surface area (i.e., work surface, panel surface, storage surfaces, etc.) is a desirable goal. However, given the varied emission properties of the many materials used in office furniture, no combination of percentages of panel surface, work surface, and storage surface area constitutes an obvious “worst-case” situation for all materials. Therefore, to define a standardized office workstation, the average combination of panel, work surface, and storage surface areas as a percentage of total workstation surface area were chosen from workstations with the 50th percentile workstation footprint.

To determine vertical *panel surface area*, both faces of furniture system panels (i.e., partitions or screens) are included, edges are ignored, and all panel surface is assumed to be exposed. All panels present on each floor plan are included, even if they are part of a shared space or open plan conference area. For freestanding (i.e., non-panel-supported)

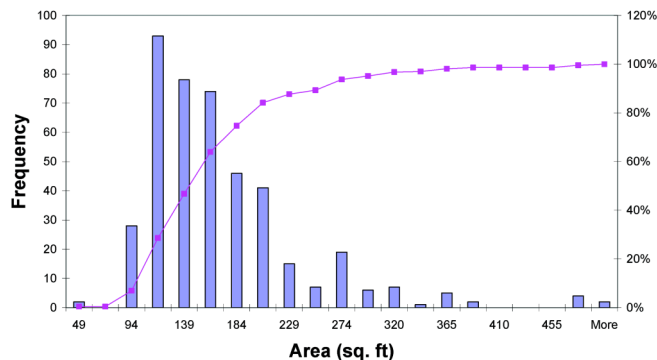


Figure 4 Private office workstation floor area (without apportioned common office space; $n = 430$).

furniture with desks and casegoods (i.e., modular cabinets), panel surface area is defined to include modesty panels, desk screens, gables, and end panels of desks or return units.

To determine *work surface area*, both the top and bottom of work surfaces are included, edges are ignored, and all surfaces are treated as exposed. All work surfaces and conference tables located within the office area, including in the office common area, are included.

To determine *storage external surface area*, all six surfaces (i.e., top, bottom, front, back, and two sides) are treated as exposed for flipper door overhead cabinets, storage cabinets, wardrobe cabinets, drawer pedestal files not located under a work surface, and lateral files not located under a work surface. For drawer-pedestal or lateral files located beneath a work surface, five surfaces (i.e., bottom, front, back, and two sides) are included (this excludes the top surface, as it is created by the work surface). For credenzas and freestanding two-drawer lateral files, their top surfaces are counted as work surface, not as external storage area, to allow for comparisons of usable work surface between workstation sizes and configurations. For shelves, the total horizontal surface area (i.e., top and bottom) is included, but edges, end panel structures, or supports are excluded for consistency. All storage within the office area perimeter, including shared banks of files in aisles, is included.

Based on this analysis (see Figure 3), for new open plan workstations the 50th percentile workstation floor area size is 3.34 m^2 (36 ft^2). To investigate if the largest building floor plans with the most workstations analyzed were inappropriately influencing the distribution of workstation size, the data set was reanalyzed while excluding the two largest floor plans, but the results still showed the highest percentage of workstations were in the range from 2.97 to 3.72 m^2 (32 to 40 ft^2). To include a reasonable sample of workstations in the determination of the 90th percentile total workstation surface area, all of the workstations with floor areas within plus or minus one-third of the standard deviation of the distribution were included. This equated to $36 \pm 6.4 \text{ ft}^2$, which included open plan workstations with floor area in the range from 29.6 to 42.4 ft^2 . For new private office workstations the 50th percentile workstation

floor area is 13.47 m² (145 ft²) and 1/3 standard deviation is 2.1 m² (23 ft²). Applying the same logic, private office workstations with floor areas between 11.3 and 15.6 m² (122 and 168 ft²) were included in the calculation for 90th percentile total workstation surface area. This resulted in a total of 1982 open plan workstations and 142 private offices from which 90th percentile total workstation surface areas were calculated.

To determine the floor area of associated common office space for each workstation, the apportioned common area as percent of open plan or private office (see Equation 3 and Table 2) from each floor plan was used as shown in Equation 4, below.

Equation 4 calculates workstation size (floor area) with apportioned common area:

$$\text{Workstation size with common area} = \frac{\text{Workstation size}}{\text{size}} \times \left(1 + \frac{\text{Common area}}{\text{percent added}}\right) \quad (4)$$

Open plan workstations share furniture system panels (i.e., partitions or screens) between workstations in clusters (i.e., four, six, and eight packs of workstations); therefore, including both sides of panels when determining panel surface area of individual workstations overstates the actual amount of panel surface area per workstation, as recognized by some furniture emissions requirements (California 2000; BIFMA 2005; California 2006) and is shown in Figure 5.

Therefore, any of the individual workstation panel surface areas that did not take panel sharing into account were corrected by multiplying the overstated panel surface area for the individual workstation by the ratio of the total actual panel surface area, divided by the overstated panel surface area within the open plan area of each floor plan. For example, the California (2006) tiled workstation individually has 319 ft² of panel surface area but only 220 ft² of panel area when used in a six pack. The ratio of actual to overstated area is 220/319 = 69%.

The surface area of all furniture present in the office common space of each floor plan was also recorded and, just as common office floor area was apportioned to each workstation, the panel, work surface, and storage surface area present in the common office area was also apportioned to each workstation. For the open plan workstations within the 50th percentile size range specified, there was no panel surface

area present in the common office space. For the private office workstations within the 50th percentile size range specified there was no additional panel, work surface, or storage area present in the common office space. The resulting 90th percentile, representative “worst case” standard workstation surface areas are noted in Table 3.

A wide range of office furniture workstation types can meet these area targets as documented in Appendix 2 of BIFMA M7.1-2005. The supporting data for the open plan workstations and private offices are shown in Table 4 and Table 5. For the open plan workstations within the 50th percentile range, the weighted average floor area with apportioned common space is 63.48 ft². Therefore 64 ft² was chosen as the floor area for a standard workstation with a 36 ft² footprint with associated common space. For the private offices within the 50th percentile range, the weighted average floor area with apportioned common space is 253.22 ft². Therefore, 256 ft² was chosen as the floor area for a standard private office workstation with a 144 ft² footprint with associated common space.

COMPARISON TO EXISTING OFFICE ENVIRONMENT MODELS

To facilitate a comparison to historical office environment models, the chamber test results for panel, work surface, and storage components of two example open plan workstations are provided in Table 6. Note the storage components are constructed of powder-coated metal that is extremely low emitting for formaldehyde.

Estimated formaldehyde concentrations for these two example open plan workstations using each office environment model are shown in Table 7. These models use a variety of different parameters and assumptions, and most do not use airflow rates based on ASHRAE 62.1-2004. Of course, other materials and combinations could produce different concentrations.

These two example workstations illustrate that for workstation materials with known emission factors, each model will predict different concentrations (e.g., a work surface construction with a formaldehyde emission factor of 100 ug/m²·h determined from chamber testing will produce very different predicted concentrations depending upon which office environment model is used). The lack of uniformity between office

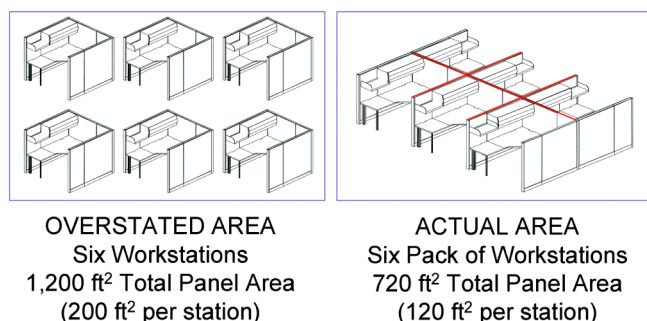


Figure 5 Panel sharing reduces surface areas.

Table 3. Standard Workstation Surface Areas A₀

Workstation System Type	Panel Area	Work Surface Area	Storage Total External Area	Total Workstation Area
Open plan	11.08 m ² (119.3 ft ²)	6.103 m ² (65.69 ft ²)	4.569 m ² (49.18 ft ²)	21.76 m ² (234.2 ft ²)
Private office	7.633 m ² (82.16 ft ²)	6.734 m ² (72.48 ft ²)	10.55 m ² (113.6 ft ²)	24.92 m ² (268.3 ft ²)

Table 4. Open Plan Workstations with 50th Percentile Floor Area

Workstation ID	Quantity of Workstations on Plan	Floor Area of Single Workstation, ft ²	Floor Area of Single Workstation with Share of Common Area, ft ²	Panel Area of Single Workstation OVER STATED, Does Not Include Panel Sharing, ft ²	Panel Area of Single Workstation Corrected for Panel Sharing, ft ²	Work Surface Area of Single Workstation, ft ²	Work Surface Area of Single Workstation with Common Space, ft ²	Storage External Surface Area of Single Workstation, ft ²	Storage Surface Area of Single Workstation with Common Space, ft ²	Total Emitting Surface Area—WITH Common Contents, ft ²
22 pd17	1	42.25	104.0	72.85	40.90	47.93	47.9	127.67	127.7	216.5
18 op7	2	36	71.6	150.6	101.54	58.2	60.6	38.9	62.4	224.5
16 op4	2	39	47.6	n/a	118.70	38.90	38.9	110.99	153.6	311.2
16 op3	3	39	47.6	n/a	109.30	38.90	38.9	110.99	153.6	301.8
28 sh2	4	37.5	63.4	13.5	8.36	42.5	42.5	71.6	85.1	136.0
16 op5	4	39	47.6	n/a	84.70	38.90	38.9	110.99	153.6	277.2
10 cl4	4	39	46.7	129.50	79.16	48.87	53.2	37.67	90.2	222.6
19 sh	4	40.5	65.0	181.5	72.30	30.0	30.9	60.2	67.5	170.8
30 op5	8	36	69.5	130.0	129.52	41.0	41.0	72.6	73.5	244.1
18 op2	9	33	65.7	161.2	108.68	40.2	42.6	38.9	62.4	213.7
10 cl8	24	39	46.7	129.50	79.16	48.87	53.2	37.67	90.2	222.6
31 op2	39	39	74.5	346	233.12	45	45.1	29.5	30.1	308.3
10 cl10	40	39	46.7	129.50	79.16	48.87	53.2	37.67	90.2	222.6
16 op2	42	39	47.6	n/a	84.70	38.90	38.9	110.99	153.6	277.2
16 op1	56	39	47.6	n/a	72.20	38.90	38.9	110.99	153.6	264.7
18 op3	67	36	71.6	188.7	127.22	42.2	44.6	38.9	62.4	234.2
29 sh	114	32	51.2	104.5	62.23	32.475	32.9	40.7	47.9	143.1
27 op1	253	35	75.2	153.0	97.10	49.0	49.7	41.9	41.9	188.7
28 ca	372	30	50.7	98	60.52	35.8	35.8	16.9	30.3	126.7
31 op1	934	36	68.8	105	70.75	41	41.1	14.8	15.4	127.2

environment models demonstrates the difficulty in comparing results across various programs and highlights the need for a standard model.

As total workstation emission concentrations are a combination of the various materials used (i.e., panel, storage, and work surface), no model predicts the highest concentration for all situations. But the ratios of airflow to surface area provide a relative indication of each model’s stringency (lower ratios are more stringent) for each surface type (panel, work surface, or storage). Referring to Equation 1, for a maximum allowable concentration (C), the maximum allowable emission factor (E) is equal to the allowed concentration multiplied by the ratio of airflow (Q_o) divided by surface area (A_o). Therefore, a lower ratio of airflow rate to surface area requires a lower emission factor. Based on this analysis, the California

2000 model is the most stringent for panel surface emissions with a ratio of 0.82, the BIFMA M7.1-2005 model is the most stringent for work surface emissions with a ratio of 2.46, and the California 2006 tiled workstation model is the most stringent for emissions from storage components with a ratio of 1.67 (highlighted in bold in Table 7.).

CONCLUSIONS

The representative, “worst case” standard *open plan* office environment for a single workstation system is defined as 5.94 m² (64 ft²) floor area by 2.74 m (9 ft) high (576 ft³ or 16.3 m³), accounting for a standard 1.83 × 1.83 m (6 × 6 ft) open plan workstation system, traffic area, and support space for shared copiers, files, storage, etc. The space is assumed to be occupied by a single occupant and has an outdoor, clean air

Table 5. Private Offices with 50th Percentile Floor Area

Workstation ID	Quantity of Workstations on Plan	Floor Area of Single Workstation, ft ²	Floor Area of Single Workstation with Shared Common Area, ft ²	Panel Area of Single Workstation, ft ²	Work Surface Area of Single Workstation, ft ²	Storage External Surface Area of Single Workstation, ft ²	Total Emitting Surface Area, ft ²
8 pmgra	12	122.5	248.22	60	32.75	74.6	167.4
8 pmgrb	1	122.5	248.22	60	32.75	74.6	167.4
18 p1	3	125	248.20	39.8	69.5	54.1	163.3
30 p7	1	125	241.66	146.7	66.8	131.0	344.4
24 p1spv	27	129	223.64	113.2	27.5	95.2	235.9
17 p1821	1	129.38	203.38	128.65	55.10	177.71	361.5
17 p1830	1	129.38	203.38	129.38	55.63	177.71	362.7
11 pmgrc	1	132	206.36	40	25	74.6	139.6
3 p1fin	8	132	229.74	82.5	60.0	120.5	263.0
7 p2	1	132	289.05	98.7	63.9	111.3	273.8
17 p1851	1	132	207.50	126.32	55.63	116.53	298.5
17 p1823	1	132	207.50	128.65	55.63	177.71	362.0
18 p2	3	140	277.99	39.8	69.5	54.1	163.3
21 p1	6	143	274.26	0.00	91.60	101.47	193.1
17 p1837	1	144	226.37	128.65	55.63	177.71	362.0
9 pmgr	4	145	214.46	20	32.8	74.6	127.4
2 p2	1	145	192.71	102.0	70.0	294.2	466.2
28 pdir	1	155	262.07	129.1	96.9	106.8	332.8
26 pass	41	160	290.02	63.55	85.83	94.77	244.1
20 p610	17	161	239.35	69.42	81.83	117.01	268.3
20 p624	9	168	249.75	69.42	81.83	117.01	268.3
30 p1	1	168	324.79	109.2	73.8	135.7	318.7

Table 6. Formaldehyde Emission Factors of Open Plan Workstation Components

Open Plan Workstation	Panel Emission Factor, ug/m ² ·h	Work Surface Emission Factor, ug/m ² ·h	Storage Emission Factor, ug/m ² ·h
1	50	100	Not detected.
2	50	15	Not detected.

ventilation rate of 4.17 L/s (8.84 cfm) in accord with ASHRAE Standard 62.1-2004.

The representative, “worst case” standard *private* office environment for a single workstation system is defined as 23.78 m² (256 ft²) floor area by 2.74 m (9 ft) high (2304 ft³ or 65.2 m³), accounting for a standard 13.38 m² (144 ft²) private office workstation system, traffic area, and support space for shared copiers, files, storage, etc. The space is assumed to be occupied by a single occupant and has an outdoor or clean air ventilation rate of 9.63 L/s (20.4 cfm) in accord with ASHRAE Standard 62.1-2004.

The office environments established from this study incorporate the well-documented trend to smaller workstation sizes, include a conservatively high (90th percentile) amount of total furniture surface, and utilize the minimum amount of outdoor, clean airflow rate in accord with the latest (2004) ASHRAE requirements. These office environments are in some cases more stringent than other historical models, are clearly based on actual buildings, and represent a “worst case” condition for current office furniture settings.

Ideally all office furniture emission programs should use the same occupant exposure scenarios to allow direct comparison of chamber test results across furniture types, manufacturers, and certification programs.

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Table 7. Office Environment Models Comparison*

Parameters	WA 1989	EPA 1996	CA 2000	BIFMA 2003	Greenguard	CA 2006	BIFMA 2005
Workstation footprint and common area (m ²)	8.92	—	12.08	12.08	13.27	12.08	5.95
Modeled space volume (m ³)	25.5	25.7	33.0	33.0	32.0	33.0	16.3
Modeled airflow rate (cfm)	15.0	15.1	9.8	19.5	15.2	12.0	8.8
Modeled airflow rate (ACH)	1.0	1.0	0.5	1.0	0.8	0.6	0.9
Q ₀ , modeled airflow rate (m ³ /h)	25.49	25.70	16.57	33.00	25.60	21.00	15.02
Panel area (m ²)	26.26	25.33	20.13	20.13	23.88	20.44	11.08
Airflow rate/panel surface area	0.97	1.01	0.82	1.64	1.07	1.03	1.36
Work surface area (m ²)	9.40	6.75	5.57	5.57	6.38	5.27	6.10
Airflow rate/work surface area	2.71	3.81	2.97	5.92	4.01	3.99	2.46
Storage area (m ²)	7.20	8.53	8.59	8.59	10.64	12.54	4.57
Airflow rate/storage surface area	3.54	3.01	1.93	3.84	2.41	1.67	3.29
Total—surface area (m ²)	42.9	40.6	34.3	34.3	40.9	38.2	21.8
Workstation 1 Formaldehyde (ppb)	72.06	61.59	76.95	38.63	58.32	60.10	63.19
Workstation 2 Formaldehyde (ppb)	46.50	43.38	53.64	27.03	41.05	42.73	35.04

* Model criteria for the BIFMA M7.1-2005 open plan workstation, the GEI (Greenguard Environmental Institute) panel-based workstation, and the California (2006) tile-based panel workstation were used. Accessories (e.g., keyboard trays, lighting, tackboards, etc.) and sink effects were not included. As of March 2007, GEI and the State of California have updated model parameters that due to time constraints are not included here. As stated earlier, the California model parameters have been updated to utilize those of the BIFMA M7.1 test method.

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